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Application of geographical information system to site selection of small run-of-river hydropower project by considering engineering/economic/ environmental criteria and social impact

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ABSTRACT

In the process of site selection of a small run-of-river hydropower project in Thailand, some problems are addressed as follows: the accessibility of the possible sites which are mostly located in rural and mountainous areas, the large amount of data required, and the lack of participation of the local people living nearby. In order to cope with these problems, this study proposes a new method to select feasible sites of small run-of-river hydropower projects by using Geographic Information System (GIS) technology. A combination of engineering, economic, and environmental criteria, as well as social impact is employed in this study. The selected study area is the upper Nan river basin situated in the north of Thailand. For the engineering criteria, the project locations are found by GIS in visual basic platform, and then economic evaluations of the selected projects are performed. Next, the environmental parameters are used to rank the projects by total weighted scores. Finally, a social impact study at the potential sites is conducted based on the public participation process, i.e. questionnaire survey and focus group discussions. The applicability of the proposed method is verified by the results of site selection of the small hydropower projects located on the Nan river basin in Thailand. This case study can be the model for the process of site selection of similar projects.

Contents

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1. Introduction

The major energy sources used to generate electricity in Thailand are natural gas, coal and oil, which are mostly imported from other countries. The use of these fossil energy sources contributes to environmental problems such as global warming, acid rain, and desertification. Under these circumstances, demands for the development of non-fossil energy sources grow significantly. Hydropower is one of renewable energy sources that do not emit the carbon dioxide and other flue gases that contaminate the environment. It has the least adverse environmental impact (i.e. greenhouse gas, SO_2, NO_x emission) and has the most energy payback ratio when compared among all electricity generation systems [1]. One GWh of electricity produced by small hydropower means a reduction of CO_2 emissions by 480 tons [2].

A small-scale run-of-river project is a kind of hydropower project that generates electricity according to the available hydrological fluctuations of the site [3]. To date there is still no internationally agreed definition of small hydro, the upper limit varies between 2.5 and 25 MW. A maximum of 10 MW is the most widely accepted value worldwide [4–6]. The benefits of small hydropower projects are ease of smaller investments, shorter period for planning and construction, use of a smaller area, use of local labor and material, and cheaper generation cost as compared to other power projects [7]. The power generation cost of small hydropower is higher than larger sized plants due to economy of scale of some instrumentation, control and monitoring systems [2].

Previous researchers in small hydropower project development research, i.e. Dudhani et al. [7] proposed a methodology to investigate potential sites of small hydropower projects in India by using remote sensing data which is used for extraction and mapping of water resources and its associates such as inhabitation and settlement pattern, forest and vegetation coverage, snow coverage and selection of probable sites for small hydropower projects. They did not include hydrologic analysis and economic analysis in their study. Kaldellis [8] investigated the existing and the proposed small hydropower plants in Greece by considering technical and economic factors. They found that the main obstacle to construction of a project was decision-making problems which include the administrative bureaucracy, the absence of a rational national water resources management plan and the over-sizing of the proposed installations. Tsoutsos et al. [9] presented the procedure of spatial planning by integrating social, economic, and environmental factors in countries with a complicated administrative and legislative system. Ramachandra and Shruthi [10] presented a Geographic Information System (GIS) application to assess small hydropower resources in a region of India by collecting the existing data of distribution and capacity of small hydropower. Belmonte et al. [11] proposed to use GIS for mapping of potential source of small hydropower by calculating of topographic drop and the annual mean flow. They did not consider economic and social aspects in their study.

Site selection with the aid of GIS technology is a widely used procedure in a variety of fields. The role of GIS in spatial decision-making is to aid the decision-maker in designating priority weights to the criteria, to evaluate the feasible alternatives and to visualize the results of the choice [12]. Melo et al. [13] used multi-criteria analysis and integrated spatial information for decision-making in the assessment and selection process of areas suitable for landfill implantation. Forzieri et al. [14] proposed GIS mapping to select the optimal sites for small dam installation. They used both qualitative and quantitative criteria which were based on satellite, hydrological, and climatological data.

Public participation is the process in which the concerns, needs and values of the people are merged into the decision-making process of the government and the private sector as a two-way communication and interaction that produces a better overall result because of support by the people [15]. It is important to bring public values, social objectives and preferences into the decision-making process at the beginning of the project study [16]. The World Bank has set public participation through an Environmental Impact Assessment as a precondition for the receipt of funding support [17]. Sections 57 and 67 of the 2007 Constitution of Thailand [18] emphasize the public right to participate. One public participation method is focus group discussion, a relatively informal discussion on a specific topic or issue [19]. This method involves qualitative data collection by group conversation, led by a moderator or facilitator. There are 6–12 participants in each group, who are selected from the assigned target population and brought together based on pre-specified qualifications [20].

In this study, public participation techniques are used for data collection to help explain social impact. Social impacts are changes that occur in people's everyday life, livelihood, culture or heritage and community from the implementation of a project, program, policy or plan. It is often not possible to predict exactly what will happen to people and their community as a result of a development project. It is possible to provide an estimate and understanding of what might happen, why and what should be done to prevent harm, and to respond to the needs and concerns of those people who might be affected [21].

In the site selection of the small hydropower project, a conventional method using manual operation is quite time-consuming. Also, in some cases, a field survey must be conducted, and it requires significant manpower due to the undulating topography, dense forest cover and bad climatic conditions at the site. The conventional method of site selection focuses on engineering and economic criteria, disregarding environmental criteria and social impact. In order to reduce cost and time consumption for the site selection, and to integrate all criteria (engineering, economic, environmental, social impact) into the decision-making process, this study proposed a new method using GIS application with the consideration of engineering, economic, and environmental criteria, and social impact. This proposed method comprises the following steps: (1) engineering analysis by discharge analysis and GIS application to locate project sites, (2) economic analysis by GIS application to evaluate the economic potential of each project, (3) ranking of the selected sites by total weighted scores of environmental parameters, and (4) social impact study through a public participation process, including interview questionnaire survey and focus group discussion.

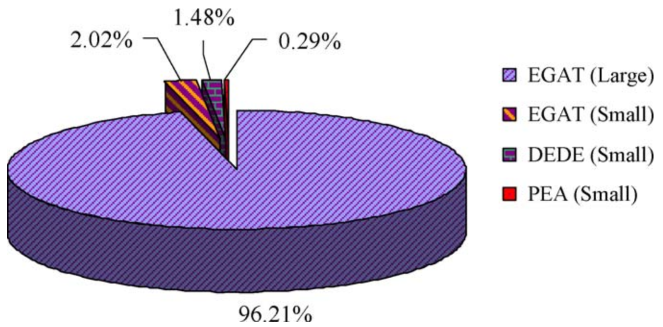

Fig. 1. Thailand's percentage of hydropower installed capacity by each organization.

2. State of hydropower in Thailand

In Thailand, the installed capacity of hydropower is 13.2% of total installed capacity which was 28,522.5 MW as of July 2007 [22]. There are three organizations responsible for hydropower development: Electricity Generating Authority of Thailand (EGAT), Provincial Authority of Thailand (PEA), and Department of Alternative Energy Development and Efficiency (DEDE) under the Thai Ministry of Energy. EGAT is responsible for large-scale and small-scale projects, whereas PEA and DEDE are responsible for only small-scale projects. Based on installed capacity, hydropower can be classified into four types: micro (below 200 kW), small or mini (200–6000 kW), medium (6000–20,000 kW), and large hydropower (above 20,000 kW) [23]. The percentage of hydropower installed capacity by each organization is shown in Fig. 1.

3. Small run-of-river hydropower project

Run-of-river project is classified into two types: low head and high head. Low head type is typically used for a large river with a gentle gradient. High head type is typically used for a small river with a steep gradient [3,24]. Since the present study focuses on small run-of-river hydropower, the high head type is considered here. The components of a small run-of-river hydropower project are shown in Fig. 2. For high head run-of-river hydropower projects, a portion of a river's water is diverted from intake at a weir. The weir is a barrier across the river which maintains a continuous flow through the intake. The water passes through a headrace or pipeline to a surge tank, in which the water is slowed down sufficiently for suspended particles to settle out. Because the turbine will be damaged by debris such as stones, timber etc., a trash rack is settled in the surge tank for protection. When the water flows through penstock or pipeline from the surge tank to the turbine that is installed in the powerhouse, the flow of water will rotate the turbine to generate electricity. The spent water from the turbine carries back to the river by a tailrace or a canal. In a run-of-river scheme, the turbine generates electricity as and when the water is available and provided by the river [5].

4. Methodology

4.1. Study area

The study area is the upper part of the Nan river basin, where the Nan City (Province) is located. This area is situated in the north of Thailand on the upstream side of Sirikit dam reservoir, which is one of the large hydropower resources in Thailand. In this upper part, the geography is a mountainous area consisting of small plains and valleys. The elevation of mountainous areas ranges from 400 to 1000 m MSL, and the area is approximately 13.026 km^2 [25]. The location of the upper Nan river basin is shown in Fig. 3.

4.2. Analysis framework

In this study, the algorithm to identify and assess the potential sites of small run-of-river hydropower projects can be classified into four criteria: engineering, economic, environmental, and social impact. Engineering and economic analysis are developed in the visual basic (VB) platform and analyzed in ArcView 9.2 GIS software with its extension spatial analyst [26]. VB is an object-oriented programming language used to program ArcObjects which are a set of computer objects specifically designed for programming with ArcGIS [27]. Engineering analysis is composed of discharge analysis by regional flow duration models, and GIS application to screen the possible areas to locate weir, powerhouse, surge tank, headrace, and penstock. Economic analysis includes calculation of cost and benefit of the engineering feasible projects, and evaluation of economic factors. Study of environmental

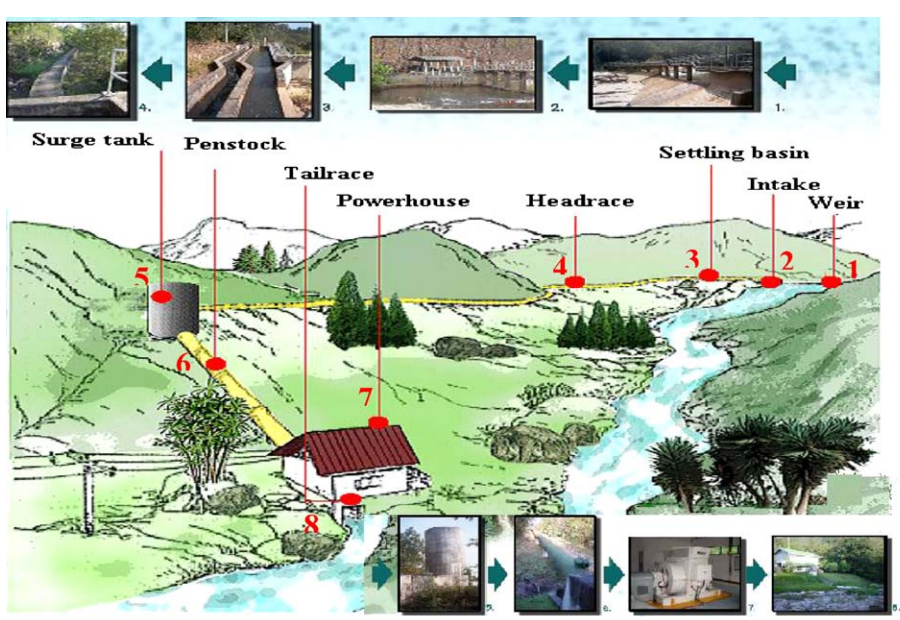

Fig. 2. Components of a small run-of-river hydropower project.

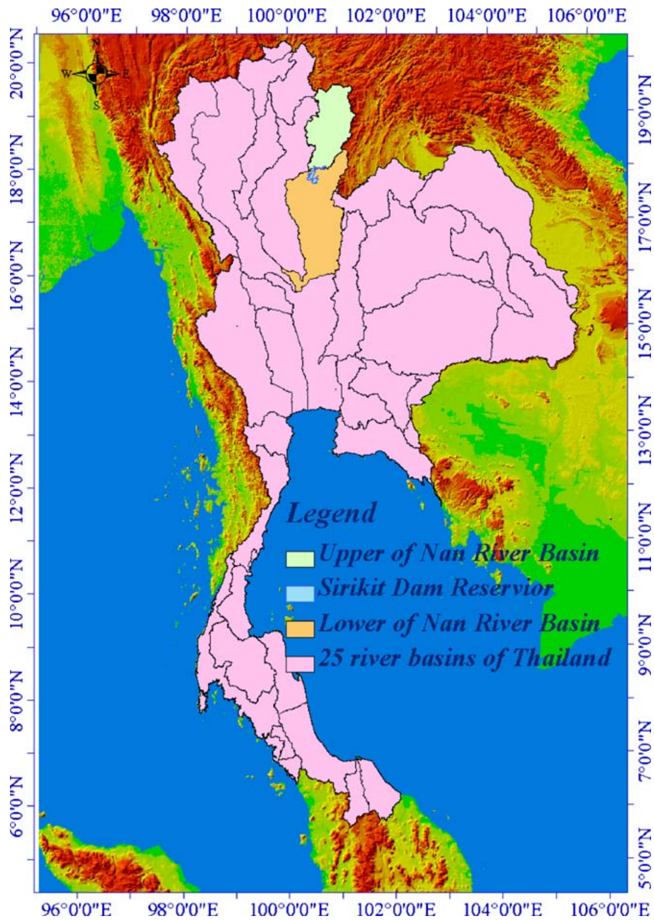

Fig. 3. Location of the upper Nan river basin of Thailand.

criteria is performed by the weighted linear combination approach using GIS [28]. Social impact is studied by using public opinion surveys and focus group discussions with the local people. The analytical framework is expressed in Fig. 4.

4.3. Engineering analysis

Engineering analysis can be separated into two main parts, discharge analysis and GIS analysis to investigate engineering potential site.

4.3.1. Discharge analysis

There are commonly no flow gauges at the proposed project site. Therefore, the flow duration relationship at the site is estimated by the information from nearby gauging stations available in the same river basin. In this study, monthly discharge records are collected from five gauging stations belonging to the Royal Irrigation Department and Department of Water Resources of Thailand. Drainage areas of these stations are in the range of 113–2099 km^2, and data record duration is 8–38 years. Streamflow at weir sites can be estimated by the two methods: regional flow duration model method, and conventional method. The step of work for each method can be expressed as follows:

(1) Regional flow duration model method

In this section, the method of developing the regional model is described [29]. Flow duration curves (FDC) are constructed as the relationship between monthly flow (Q) versus the percentage of time during the period analyzed in which the particular flow is equaled or exceeded (D), and also the relationship between the ratio of Q and mean annual flow ($\bar{Q}$) or dimensionless discharge ($Q/\bar{Q}$) versus D. The flow duration curves models for calculating discharges at ungauged sites in the upper Nan river basin can be expressed in the forms of logarithmic, cubic, and exponential equations as follows:

$$Q = (15.802 + 0.1563A) - (3.7779 + 0.0353A)\ln(D) \tag{1}$$

$$Q = (14.854 + 0.1363A) - (0.735 + 0.0058A)D + (0.0117 + (9 \times 10^{-5})A)D^2 - ((4 \times 10^{-7}) + (8 \times 10^{-5})A)D^3 \tag{2}$$

$$Q = (12.18 + 0.0922A)\exp((-0.0429 + (4 \times 10^{-6})A)D) \tag{3}$$

$$Q/\bar{Q} = (5.9922 - 0.0002A) - (1.3788 - (5 \times 10^{-5})A)\ln(D) \tag{4}$$

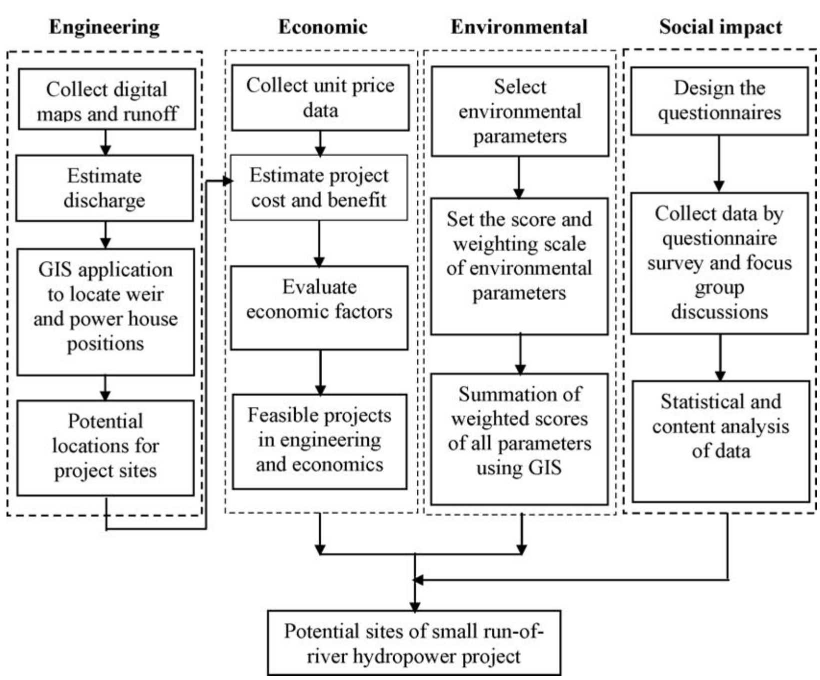

Fig. 4. Analytical framework of the study.

Table 1
Representative $Q/\bar{Q}$ at percentage of time 10–100 for the upper part of the Nan river basin.

Station	Percentage of time									
	10	20	30	40	50	60	70	80	90	100
N.42	2.76	1.59	1.13	0.64	0.41	0.29	0.23	0.21	0.17	0.12
N49	3.10	1.96	0.94	0.45	0.25	0.18	0.13	0.11	0.08	0.04
N65	2.90	1.61	0.89	0.73	0.46	0.32	0.24	0.18	0.14	0.08
090201	2.73	1.81	1.03	0.59	0.38	0.23	0.18	0.14	0.10	0.06
090203	2.75	1.81	1.09	0.64	0.42	0.28	0.23	0.19	0.14	0.05
Average	2.85	2.85	1.76	1.02	0.61	0.39	0.26	0.20	0.17	0.13

$$Q/\bar{Q} = (5.3417 - 0.0002A) - (0.2394 - (1\times10^{-5})A)D + (0.0036 - (2\times10^{-7})A)D^2 - ((2\times10^{-5}) + (2\times10^{-9})A)D^3 \quad (5)$$

$$Q/\bar{Q} = (3.9106 - 0.0003A)\exp((-0.0429 + (4\times10^{-6})A)(D)) \quad (6)$$

where A is drainage area.

The models of $\bar{Q}$ to be used in each of Eqs. (4)–(6) are expressed by three forms of equations: power, linear, and cubic equations given in Eqs. (7)–(9), respectively.

$$\bar{Q}_{\text{power}} = 0.1616A^{0.7537} \quad (7)$$

$$\bar{Q}_{\text{linear}} = 2.1562 + 0.0281A \quad (8)$$

$$\bar{Q}_{\text{cubic}} = 28.155 - 0.1742A + 0.0003A^2 - (1\times10^{-7})A^3 \quad (9)$$

(2) Conventional method

The methodology from previous studies [30–34] is used for calculating discharge at ungauged sites, and is described as follows: All the monthly flow data (Q) from each gauging station in the same basin are used to calculate mean annual flows ($\bar{Q}$). Then the ratios of monthly dimensionless flow ($Q/\bar{Q}$) are determined. $Q/\bar{Q}$ from every gauging station corresponding to the same percentage of time of exceedance are averaged to give a representative flow ratio for the whole basin at the particular percentage of time, as shown in Table 1.

(3) Model verification

Model verifications are required to evaluate the accuracy of the above-mentioned two methods that are developed from data of gauging stations. This can be done by comparing measured discharge and computed discharge from the two methods. In order to evaluate the accuracy of the prediction, the verification results are presented in terms of root mean square relative error [29]. From the comparison of the errors for all cases of regional flow duration model method and conventional method, it is found that the conventional method with the cubic model of $\bar{Q}$ gives the lowest error. Therefore, the model for estimating discharge at a weir site for a small run-of-river hydropower project development in the upper Nan river basin should follow the conventional method in Table 1 with the use of the value of $\bar{Q}$ in cubic model (Eq. (9)).

4.3.2. GIS analysis to investigate engineering potential site

Data used for GIS analysis are composed of digital elevation model (DEM) that is a digital representation of the continuous variation of relief over space [35], and topography maps with scale 1:50,000 from the Royal Thai Survey Department.

The investigation of the possible locations of main structures of small run-of-river hydropower projects (i.e. weir, power house, surge tank, headrace and penstock) is performed as follows:

Step 1: Setting criteria for locating project site

From previous studies [36–38], the selection of an appropriate site for small run-of-river hydropower development requires consideration of the following criteria:

(1) In order to lower the project cost, the distance between weir site and powerhouse should be located at a reasonable distance, (preferably not more than 5 km), and the length of headrace and penstock should be as short as possible.
(2) The site should be situated on a perennial stream so that the stream discharge will exist all year round.
(3) The installed capacity should be in the range between 1 MW and 10 MW in order to limit the size of small or mini hydropower plants.
(4) The surge tank and headrace should be located at the same elevation as intake.

Step 2: Watershed area delineation and calculation

In this study, DEM is used to generate a stream layer which can be used to delineate and calculate watershed area by ArcView GIS software [26].

Step 3: Designed discharge (Q_d) estimation

The value of a watershed area (A) calculated from step 2 is substituted in Eq. (9) to calculate the mean annual flow ($\bar{Q}$). Then designed discharge (Q_d) is estimated by multiplying $\bar{Q}$ with the average of $Q/\bar{Q}$ in the last row of Table 1. This study proposes to use the value of $Q/\bar{Q}$ at a percentage of time 30% to estimate Q_d, i.e. Q_{30}. This Q_{30} is chosen to be the maximum value of designed discharge because a flow greater than Q_{30} is expected only during flood period. This criterion is set to apply to all run-of-river projects connected to the PEA distribution system [39].

Step 4: Searching the location of power house

The location of power house is found by considering the difference of head between weir and power house. In order to simplify the analysis, installed capacity or power output (P) can be estimated by Eq. (10) as follows [24].

$$P = 9.81 \times \eta_t \times \eta_g \times Q_d \times (H_d - (0.001L_h + 0.005L_p)) \quad (10)$$

where P is in kW, η_t is the turbine efficiency (0.88), η_g is the generator efficiency (0.96), Q_d is the designed discharge (m^3/s), H_d is the gross head (m), L_h is length of headrace (m), and L_p is length of penstock (m).

Step 5: Finding the possible position of surge tank, headrace and penstock route line

To limit cost of the project, surge tank is located within a 5 km radius of a weir site. Headrace will be laid along the contour line of intake position. The length of penstock is the slope distance between power house and surge tank. The location of surge tank and the route line of headrace and penstock are displayed complying with the criteria of the location selection as shown in Fig. 5, and the results of engineering analysis are shown in Fig. 6.

4.4. Economic analysis

4.4.1. Criteria for the economic analysis

In this study, the cost of the small run-of-river hydropower project includes the investment cost, and the operation and maintenance cost. The investment cost consists of:

(1) Direct costs: (1.1) Preparation work, (1.2) Environmental mitigation, (1.3) Civil works, (1.4) Hydraulic equipment, (1.5) Electrical/mechanical equipment, and (1.6) Transmission line costs,
(2) Indirect costs: (2.1) Administration and engineering costs, (2.2) Contingency, and (2.3) Interest during construction.

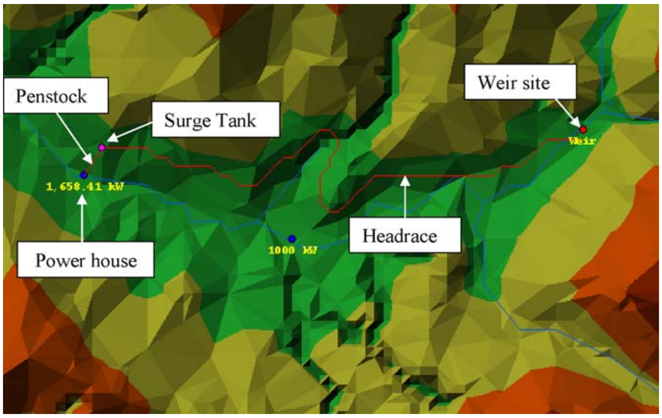

Fig. 5. The possible project locations.

In the economic analysis of the project, the following criteria are used:

(1) For the estimation of the direct costs, the quantities of all materials, equipment, and labor costs are calculated by using the empirical formula and the data of existing facilities [23,24,40–42]. The unit prices of all materials, equipment, and labor are obtained from the following sources: (a) available market prices in year 2007–2008, (b) the previous studies [23,40–42], and (c) the Comptroller General's Department of Thailand. Preparation work constitutes 5% of total civil works cost [24]. Environmental mitigation constitutes 7% of total civil works cost [42].
(2) For the estimation of the indirect costs, administration and engineering service is 15% of direct cost, and contingency is 10% of direct cost [24].
(3) Operation and maintenance cost per year of operation is composed of 1% of civil works and transmission line costs, and 2.5% of electrical/mechanical equipment costs [40,42].
(4) Discount rate or interest rate is set to be the interest of a long-term bond, and from the Bank of Thailand, the value of 8% per year is used in the present study.
(5) The price of generated electricity, i.e. energy tariff, is estimated according to the PEA announcement for renewable energy from Very Small Power Producers (VSPP) who produce not more than 10 MW in 2007, and the value of 0.0687 US$/kWh is used in this study.
(6) The small run-of-river hydropower projects can reduce carbon dioxide, therefore carbon credit is estimated from the expense in growing the forest, and the value of 0.0104 US$/kWh [41] is used here.
(7) Construction period is set to be 3 years and economic life of the project is set to be 30 years [40–42].

4.4.2. Calculation of generated energy

In order to determine the benefit of a small run-of-river hydropower project, the generated energy is calculated as demonstrated by the example in Table 2.

4.4.3. Project evaluation

Time series economic evaluation of the project is used in this study. Net present values (NPV), internal rate of return (IRR), and benefit–cost ratio (B/C) are calculated for all engineering feasible projects. The projects are said to be economically feasible, when NPV >0, $B/C>1$, and IRR $\geq 8\%$.

4.5. Environmental analysis

The process of finding a suitable small run-of-river-hydropower project site based on environmental criteria is composed of selection of environmental parameters, setting the score and weighting scale of environmental parameters, and summation of the weighted scores of all parameters.

In this study, the GIS data for environmental analysis are obtained from two agencies, the Department of Environmental Quality Promotion and the Department of Land Development of Thailand. The six environmental parameters used in this study are watershed class area, location of national park and wildlife sanctuary, land use type, population density, mean annual sediment yield, and heritage site. The score and weighting scale of the parameters are adapted from Chaisomphpb and Tanutpongpalin's study [28] as shown in Table 3 and Table 4, respectively.

Weighted linear combination is used to sum the scores of all parameters. The suitability of the project based on environmental criteria can be calculated using the following

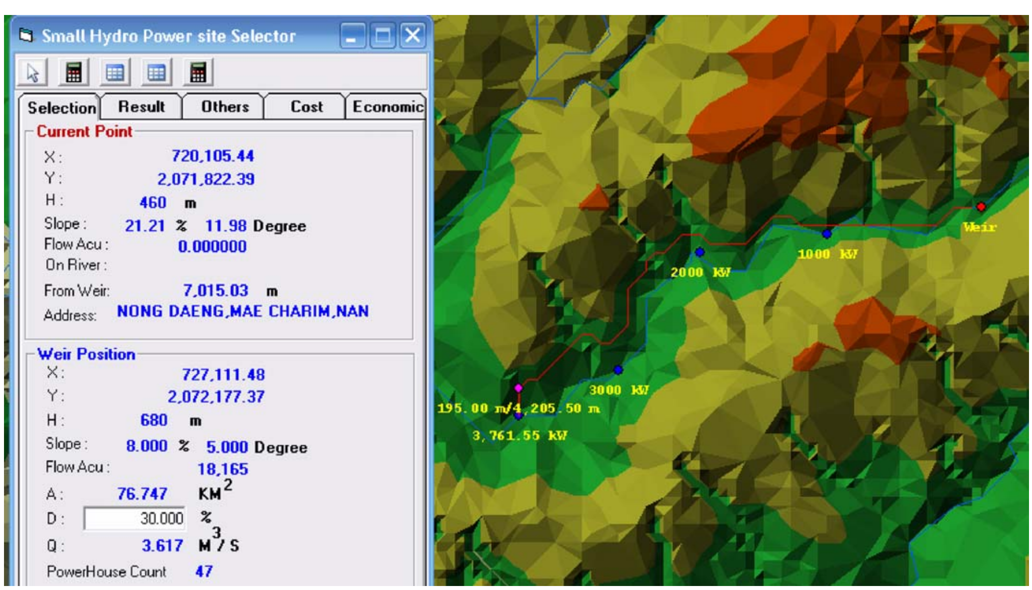

Fig. 6. Results of engineering analysis.

Table 2
Example of energy calculation for small run-of-river hydropower project.

[1] D (%)	[2] Days	[3] Difference of [2]	[4] Q (m^3/s)	[5] Mean of [4] (m^3/s)	[6] Q_t (10^6 m^3)	[7] E (10^6kWh)
30	110	110	0.567	0.567	5.390	5.280
40	146	36	0.387	0.477	1.483	1.453
50	183	37	0.292	0.339	1.084	1.062
60	219	36	0.229	0.261	0.810	0.794
70	256	37	0.178	0.204	0.651	0.638
80	292	36	0.146	0.162	0.504	0.494
90	328	36	0.116	0.131	0.408	0.400
100	365	37	0.0745	0.095	0.305	0.299
Total					10.637	10.420

Notes: $Q_d = Q_{30} = 0.567$; [6]: Q_t = [3] × [5] × 24 × 3600; [7] = annual energy generation (E) = 9.81 × 0.88 × 0.90 × [6] × ($H_d - (0.001L_h + 0.005L_p)$) × 1/3600; H_d: gross head; L_h: length of headrace; L_p: length of penstock.

Table 3
The score of environmental parameters [28].

Parameters (score(1))	Watershed class (class(2))	Wildlife sanctuary (buffer (m))	Land use type	Suspended sediment (tons/km^2)	Population density (person/km^2)	Heritage (buffer (m))
0	1A	Reserved forest	–	–	–	–
1	1B	0–2000	Forest	Above 120	Above 40	Below 500
2	2	2001–3000	Urban	101–120	31–40	501–1000
3	3	3001–4000	Agricultural	81–100	21–30	1001–1500
4	4	4001–5000	Industrial	60–80	10–20	1501–2000
5	5	Above 5000	Uninhabited	Below 60	Below 10	Above 2000

Note:

(1) Number 0 means project is prohibited in the area in which watershed class is 1A and the wildlife sanctuary is reserved forest, number 1 means significant adverse impact, number 2 means high adverse impact, number 3 means medium adverse impact, number 4 means low adverse impact, number 5 means slight adverse impact.
(2) Watershed class 1A, 1B, 2, 3, 4, and 5 are based on physical characteristics, hydrological potential and resources according to Thai regulation.

formula:

$$\text{Suitability}\,(S) = (R_1 \times W_1) + (R_2 \times W_2) + \ldots + (R_n \times W_n) \qquad (11)$$

where R is the score of each parameter, W is the weight of each parameter, and n is the number of parameters. Table 5 shows all possible cases of total weighted scores which represent the suitability of the project.

The total weighted score of each project is calculated according to Eq. (11). In order to illustrate the weighted scores simply, the scores are transformed into percentage by multiplying the total weighted score by 20 such that the full score of 5 in Table 5 is 100%. Then the degree of suitability for establishing a run-of-river type small hydropower project is ranked from the highest total weighted score to the lowest. The higher the project's score, the more suitable the project is. In this study, the total weighted score is obtained by overlaying the layers representing six environmental parameters with the spatial analyst function in ArcView GIS.

Table 4
Weighting scale of environmental parameters [28].

Parameter	Weighting scale
Watershed class	0.23
Wildlife sanctuary	0.20
Land use type	0.17
Heritage	0.14
Suspended sediment yield	0.14
Population density	0.12

Table 5
Weighted scores of environmental parameters.

Parameter	Weighted scales (W)	Rating value (R)					
		0	1	2	3	4	5
Watershed	(W = 0.23)	0	0.23	0.46	0.69	0.92	1.15
Wildlife sanctuary	(W = 0.20)	0	0.20	0.40	0.60	0.80	1.00
Land use	(W = 0.17)	–	0.17	0.34	0.51	0.68	0.85
Heritage	(W = 0.14)	–	0.14	0.28	0.42	0.56	0.70
Sediment yield	(W = 0.14)	–	0.14	0.28	0.42	0.56	0.70
Population	(W = 0.12)	–	0.12	0.24	0.36	0.48	0.60
Total	1	0	1	2	3	4	5

4.6. Social impact analysis

The following variables are used in studying social impact: socio-economic condition, the use of forest and the quality life value, change condition of household and community, small run-of river hydropower project perception, attitude toward the project, and project support. Data are collected from the respondents through a public participation process.

4.6.1. Public participation process

A public participation process is applied to this study in order to share information with the target groups, hear their comments and concerns, and consult the public on the project feasibility. This study employs face-to-face interviews based on questionnaires, focus group discussions, and exhibition of the project detail.

4.6.2. Public opinion survey

A public opinion survey is conducted in the potential areas for project development based on engineering criteria. There are two groups of samples. The first group is from simple random sampling according to the characteristics of the population: people who live within 2.5 km in radius from the projects, people who are 18 years of age and older, and the leaders of the communities such as teachers, monks, and village headmen. The sample size is obtained from Yamane equation at level of 95% confidence. The population in the Nan province was 477,662 [43], thus by using the value of sampling error equal to 0.05, 400 samples are obtained. However, 1500 samples are collected in this study to obtain more accurate

results. For the second group, purposive sampling is used. Fifty samples are selected from the representatives from government agencies, mass media, and non-government organizations (NGOs).

4.6.3. Focus group discussion

Focus group discussion is used to collect qualitative data on the villagers' concerns and perceptions about the project. The participants are the representatives of the communities directly affected by the project development. The process of focus group discussion consists of:

(1) Providing project information to the participants by using leaflets, exhibitions, models, and presentation of project detail.
(2) Asking probing questions related to the members' worries about the project.
(3) Separating the participants into small groups for discussion.
(4) Presentation of representatives from each group.
(5) Asking probing questions as to how to reduce participants' concerns about the project, who should be responsible for doing so, and how local people can get involved in the project.
(6) Separating the participants into small group for further discussion.
(7) Presentation of representatives from each group and opening for discussion.
(8) Evaluation and conclusion of the meeting.

The focus group meeting is conducted by the facilitators, who use probing questions to elicit the ideas and experiences of the members in the group. The process begins with broad questions and proceeds to specific questions. Figs. 7 and 8 show the focus group meetings held at remote villages near the potential sites in the Nan province.

5. Result and discussion

5.1. Results of feasible sites based on engineering, economic, and environmental criteria

From the results of GIS analysis, the potential sites of small run-of-river hydropower projects are located by using engineering criteria as explained in Section 4.3. The engineering feasible projects are found at 39 streams in 10 districts of the Nan province.

The engineering feasible project sites are evaluated by using economic analysis described in Section 4.4. Accordingly, there are 86 economically feasible projects sites located at 37 streams in the upper Nan river basin in 7 districts of the Nan province, i.e. Chiang Klang, Mae Charim, Pua, Thung Chang, Wiang Sa, Chaloem Phra Kiat, and Bo Kluea.

Fig. 7. Focus group meeting at the Chiang Klang district in the Nan province.

Fig. 8. Focus group meeting at the Chaloem Phra Kiat district in the Nan province.

The engineering and economically feasible projects are ranked from the highest to the lowest weighted scores according to environmental criteria. The GIS analysis as described in Section 4.5 is used to obtain the total weighted scores in percentage indicating the suitability of the project. The results of environmental analysis are shown in Fig. 9. The environmental scores are in the range of

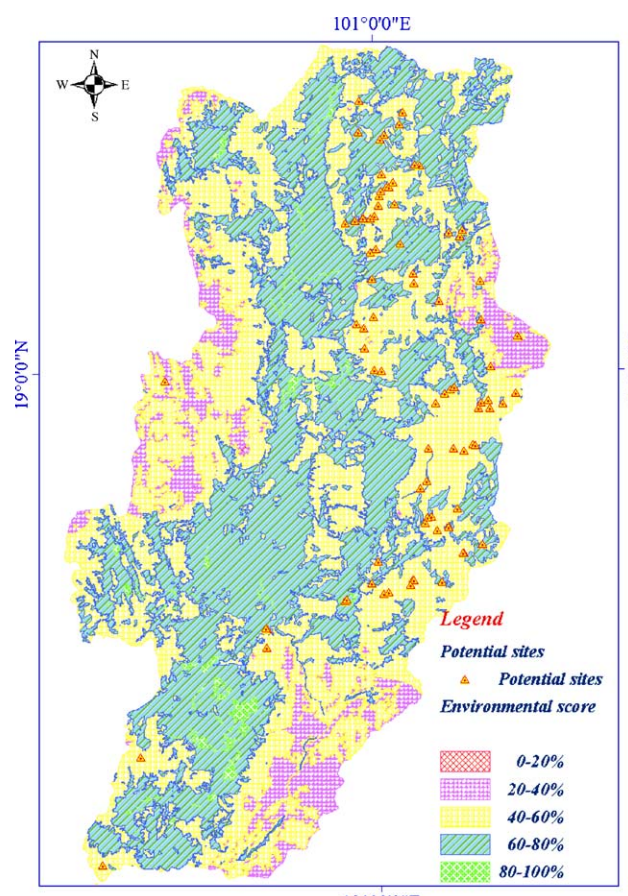

Fig. 9. Locations of potential sites in the map of environmental total weighted score.

Table 6
The first 20 feasible small run-of-river hydropower projects based on environmental criteria in the upper part of the Nan river basin.

No.	Stream	District	Head (m)	Drainage area (A)	Design discharge (m^3/s)	Power (kW)	(Million US$)	Economic factor (*B*/*C*)	Environmental score
1	Nam Wa	Wiang Sa	20	1770.47	28.23	4516.01	17.01	1.36	84.40
2	Nam Wa	Wiang Sa	20	1761.11	28.17	4507.07	18.01	1.28	84.40
3	Nam Wa	Wiang Sa	27	1704.90	27.82	6009.29	22.51	1.35	72.60
4	Nam Haeng	Wiang Sa	18	937.39	20.61	2968.18	12.85	1.01	71.59
5	Nam Wa	Bo Kluea	40	543.64	14.65	4689.09	16.43	1.16	69.60
6	Nam Wa	Bo Kluea	40	529.68	14.40	4608.95	17.42	1.07	69.60
7	Nam Haeng	Wiang Sa	19	904.89	20.19	3068.94	13.05	1.02	67.20
8	Nam Kon	Thung Chang	360	23.67	1.50	4328.58	11.92	1.36	67.00
9	Huai Sa Lao	Chaloem Phra Kiat	149	20.94	1.37	1634.24	4.61	1.32	67.00
10	Nam Hoem	Chaloem Phra Kiat	280	8.62	0.70	1576.40	4.51	1.30	67.00
11	Huai Kin	Pua	90	137.36	5.56	3999.76	11.90	1.28	67.00
12	Nam Pua	Pua	133	90.04	4.07	4331.58	12.96	1.26	67.00
13	Nam Lad	Chaloem Phra Kiat	110	45.97	2.47	2173.41	6.89	1.18	67.00
14	Huai Satun	Chiang Klang	240	15.80	1.11	2130.05	6.75	1.18	67.00
15	Nam Lad	Thung Chang	124	28.42	1.72	1709.77	6.16	1.04	67.00
16	Nam Kon	Chiang Klang	87	130.57	5.35	3725.35	11.81	1.20	65.60
17	Nam Wa	Bo Kluea	87	84.94	3.90	2713.71	7.49	1.37	64.40
18	Nam Poen	Thung Chang	500	5.40	0.49	1979.07	6.11	1.21	64.40
19	Nam Phang	Mae Charim	200	31.41	1.86	2972.67	9.45	1.18	64.20
20	Nam Pha	Mae Charim	116	22.24	1.43	1330.78	4.90	1.01	64.19

34.40–84.40. The numerical results of the first 20 feasible projects are shown in Table 6.

5.2. Comparison of the results with the previous reports

The potential sites selected according to engineering and economic criteria were compiled from the previous reports [40,44,45] to allow comparison with the results from this study. The comparisons are shown in Fig. 10. It can be seen that the locations of feasible project sites listed in the previous reports and those found through this study are generally similar. However, it should be noted that the present analysis uses newer data in its assessment of engineering and economic criteria.

5.3. Social impact analysis

5.3.1. Results from questionnaire survey

The results from the first group questionnaires are illustrated in Fig. 11 and 12 by inverse distance weighted (IDW) interpolation method in ArcView GIS. IDW is the method to estimate cell values by averaging the values of sample data points in the vicinity of each cell [26]. Fig. 11 illustrates the people's support for the project. The majority of respondents (80.9%) would support a project built in their village. Fig. 12 shows that the people's satisfaction with their living standard is low in the remote areas in the north and south of the Nan province. The people in those areas hope that a project would help develop their communities, thereby raising their standard of living.

The project locations are ranked based on the percentage of people who support a project, from the highest to the lowest, as shown in Table 7. Most of the first 20 projects have low values of economic factor and environmental score. This is due to the fact that most of the projects are situated in watershed area class 1A and reserved forest, and hence project developments are currently prohibited. In addition, high investment cost in the mountainous area lowers the value of the economic factor. Most of the people who live in these areas earn their own living by utilizing reserved forest for activities such as cultivation and farming. They think that the development of the projects will improve their lives. Therefore, the percentage of project support is high in the location of low economic factors and environmental scores.

From the above discussion, it can be concluded that social aspect should be considered in the site selection of small hydropower plants. However, in the conventional feasibility study of the project, engineering and economic criteria are used to select the most feasible project, and then the mitigation of environmental and social impacts are studied for the selected project. This study proposes that the 4 dimensions (i.e. engineering, economic, and environmental criteria as well as social impact), should be considered throughout the project development process in order to select the appropriate location. In addition, public consultation should be an integral part of the decision-making process.

5.3.2. Result from focus group discussion

The focus group discussions revealed three broad areas of concern among the participants: (1) project implementation, and project operation and maintenance, (2) living conditions of the people, and (3) environmental impact. Some of the results are presented below.

First, the concerns about project implementation/operation and maintenance are expressed as follows: The project will not be developed and the laws concerning reserved forest may make it difficult to approve the project. The construction of the project may be difficult since the landscape is mountainous, the site is narrow, and the access road would be difficult to build. Sedimentation in front of the weir may be an obstacle in maintaining the project. The project may not last long because there will be no unit responsible for project operation and maintenance.

Secondly, concerns about living conditions of the people are as follows: Because the Nan province is almost entirely mountainous and features few flat plains for agriculture, the project will have a negative effect on agricultural and residential areas. For instance, a weir may lead to water shortages for consumption and agriculture, and the headrace and penstock may affect agricultural land. In addition, unequal distribution of benefits from the project may cause conflict among the villagers.

Lastly, their concern about the environmental impact is that water resources, forest, fauna and flora, etc. may be destroyed by the project.

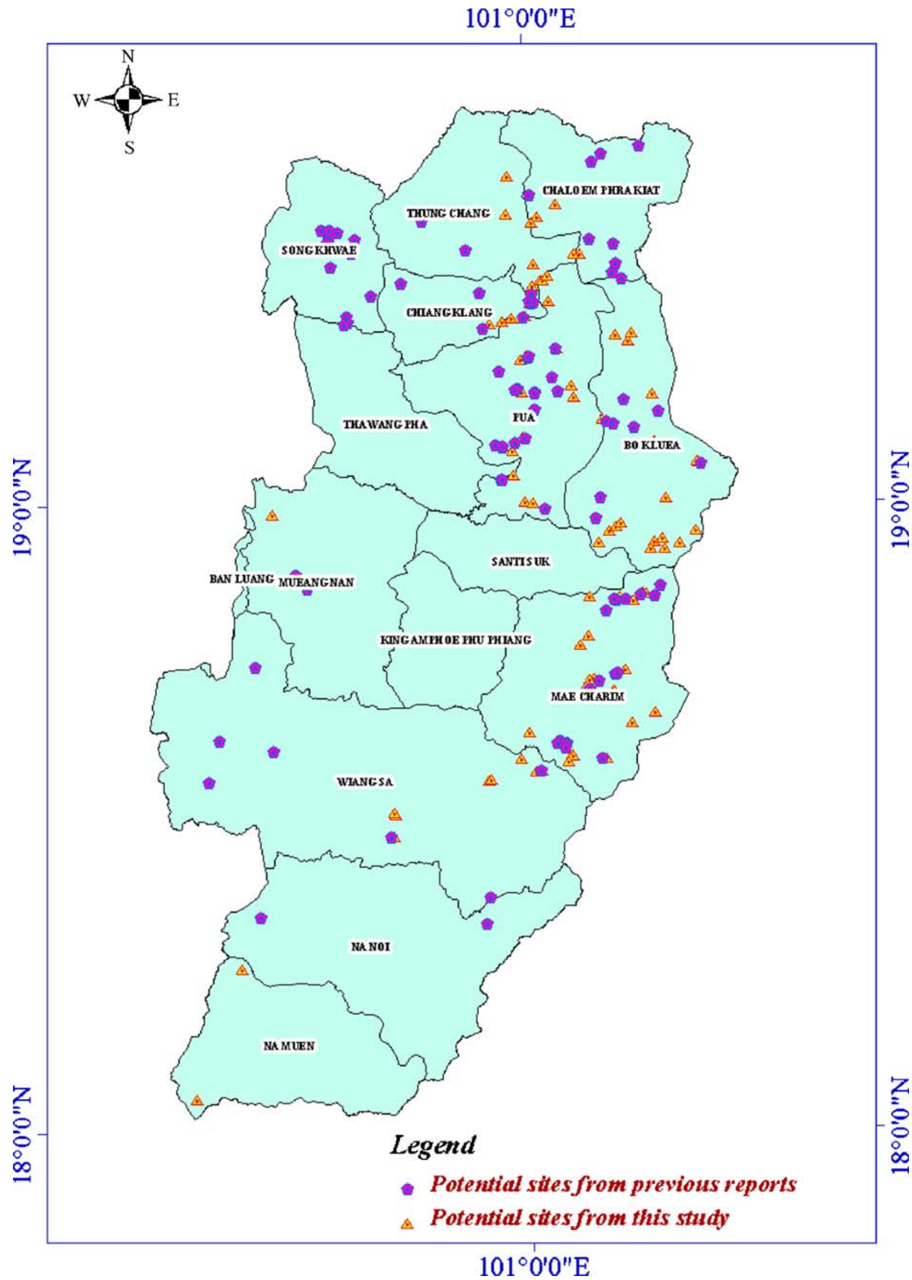

Fig. 10. Comparison of the location of potential sites listed in previous reports with those found in this study.

In addition to people's concerns, the results of focus group discussion indicate ways to reduce those concerns, which should be the responsibility of three parties: project owners, the government, and local communities. Some of the results are described below.

The project owner should be responsible for the following activities: the project owner should ensure the people's understanding of the project, provide local people with information about the project, including the advantages and disadvantages of the project, and organize a focus group meeting before starting construction in order to elicit more people's opinions on the project. The project owner should use an underground headrace and penstock in the design of a small hydropower project. The project owner should provide additional water supply to the communities by producing village tap water, encourage agriculture and fish breeding, improve the area for agricultural use, promote the project as a tourist attraction and encourage tourism activities in the village, hire a local labor force for the construction and maintenance of the facility, pay fair compensation, distribute income equally, and return the profits to the community by supporting the village fund.

The government should facilitate understanding between the project owner and local people, share information about the impact of the project with the local people, form a committee to monitor the project, recover the natural resources, reduce electricity fees for the villagers, install an accident warning system, and be the mediator in case of a problem in providing compensation for the project.

The local communities should allow project development in their area, help coordinate with nearby communities that use the same water sources, and appoint representatives of the villagers to act as an examination committee for safety and security as well as environmental protection during the project construction and operation periods.

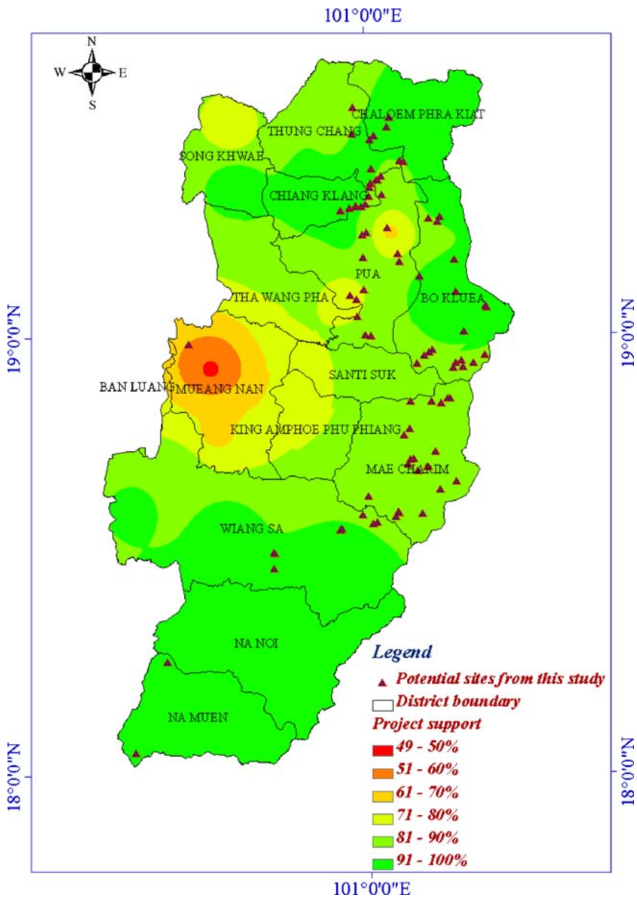

Fig. 11. Project support.

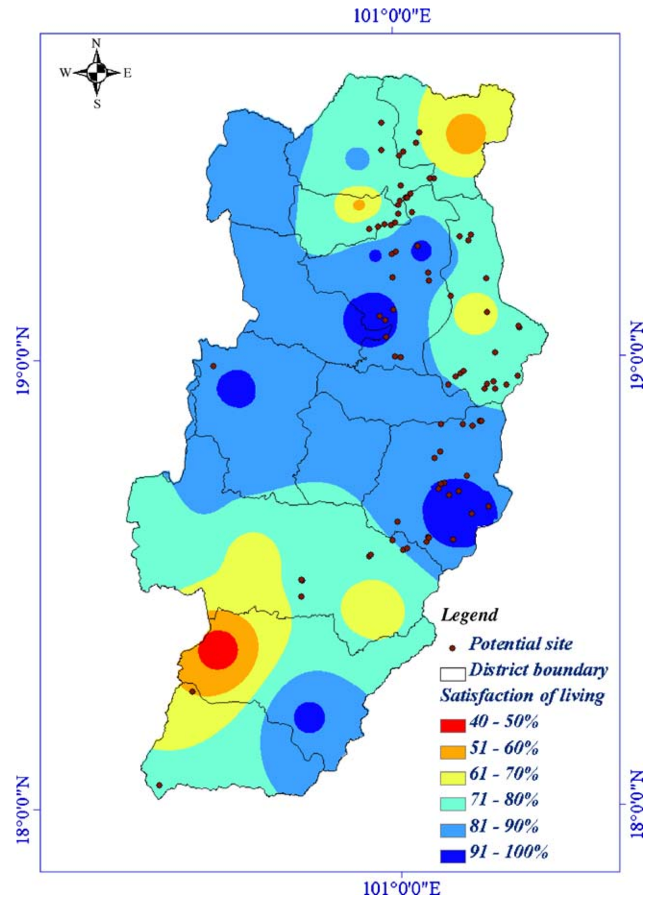

Fig. 12. Satisfaction with present standard of living.

Table 7
The 20 highest scoring locations on the basis of popular support by local people in the upper Nan river basin.

No.	Stream	District	Power output (kW)	Economic factor, B/C	Environmental score (%)	Project support (%)
1	Huai Nam Ti	Bo Kluea	1031.31	1.01	51.40	96.92
2	Nam Kon	Chiang Klang	3681.00	1.10	55.20	93.80
3	Huai Nam Un	Na Muen	1097.58	1.02	53.60	93.78
4	Nam Kon	Chiang Klang	3385.53	1.10	55.20	93.20
5	Nam Wa	Bo Kluea	3643.26	1.33	50.60	93.08
6	Nam Wa	Bo Kluea	1768.81	1.06	34.40	92.25
7	Nam Wa	Bo Kluea	2016.60	1.02	50.60	92.15
8	Nam Kon	Chiang Klang	3634.03	1.10	64.00	92.04
9	Nam Kon	Chiang Klang	3477.32	1.04	55.20	91.96
10	Nam Haeng	Wiang Sa	3028.47	1.07	42.80	91.80
11	Nam Wa	Bo Kluea	2253.50	1.13	51.80	91.72
12	Nam Phang Noi	Mae Charim	2394.85	1.04	50.60	91.59
13	Nam Wa	Wiang Sa	4516.01	1.36	84.40	91.52
14	Nam Wa	Bo Kluea	1882.32	1.05	50.80	91.52
15	Nam Wa	Mae Charim	2669.10	1.05	59.40	91.33
16	Nam Wa	Wiang Sa	4507.07	1.28	84.40	91.29
17	Nam Haeng	Wiang Sa	3068.94	1.02	67.20	91.23
18	Nam Haeng	Wiang Sa	2968.18	1.01	71.59	91.19
19	Nam Lad	Chaloem Phra Kiat	1103.08	1.47	62.20	90.89
20	Nam Lad	Thung Chang	1709.77	1.04	67.00	90.69

6. Conclusion

The objective of this research is to propose an analytical framework to identify the feasible sites of small run-of-river hydropower projects based on engineering, economic, and environmental criteria, as well as social impact, by using GIS. The study area is the region of the upper part of the Nan river basin.

The proposed methodology can be summarized as follows: Engineering analysis consists of discharge model estimation and GIS analysis to find potential sites. Discharge models for estimating discharge at weir site, i.e. flow duration curves, are developed with the use of recorded data from nearby gauging stations in the river basin. In GIS analysis, the engineering feasible project sites are obtained through the following steps: (1) setting criteria for

locating project site, (2) watershed area delineation and calculation, (3) designed discharge estimation, (4) searching for power house location, and (5) finding surge tank, headrace, and penstock locations. The engineering feasible projects are evaluated according to economic factors (*B*/*C*, NPV, and EIRR). The projects which have *B*/*C* value equal to or greater than 1.0 are considered economically feasible projects. In the environmental analysis, weight linear combination is used to calculate the total weighted scores of all environmental parameters. The environmentally feasible projects are obtained by ranking the total weighted scores of the economically feasible projects. In the study of social impact, a public participation process is employed, including both interview questionnaires and focus group discussions.

From the results of this study, the engineering feasible projects sites are found at 39 streams in 10 districts of the Nan province. There are 86 project sites that are feasible according to engineering and economic criteria. These project locations are compared with the potential sites collected from the previous reports. It is found that the sites proposed according to each method are similarly located.

Regarding the social impact study, from the results of questionnaire survey, it is found that most of the potential projects receiving the greatest support from local people are situated in the north or south of the Nan province. The majority of these areas are in conserved forest in which it is forbidden to develop any project, but most of the people support the project because they hope that the development of the project will increase their living standard. Through focus group discussion, local people's concerns and suggestions for addressing those concerns are collected. The three areas of greatest concern are project implementation, living conditions of the people, and environmental impact. It can be concluded that people will respond positively to small run-of-river hydropower project development in their communities if they can obtain project information and they have an opportunity to propose their ideas and suggestions at the early stage of project development planning through focus group discussion. Nevertheless, project owners, the government, and local communities should seek to allay the concerns of the people before starting the project.

In a conventional feasibility study, project sites are normally decided by using engineering and economic criteria. By considering the four criteria, the GIS methodology presented in this study can be used to select all potential locations of small run-of-river hydropower projects and can be applied to various study regions located in areas characterized by high topography, such as other provinces in the north of Thailand. This methodology has broader application potential, in that it can also be applied to other potential hydropower sources. It offers a quick way to examine large areas and to focus on possible locations by ranking the projects based on each criterion. A decision-maker can use the results of present study to investigate and compare the suitability of various project sites.

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References

[1] Gagnon L, Beanger C, Uchiyama Y. Life-cycle assessment of electricity generation options: the status of research in year 2001. Energy Policy 2002; 30:1267–78.
[2] ESHA (European Small Hydropower Association). Environmental integration of small hydro plants. http://www.esha.be; 2005.
[3] IEA (International Energy Agency). Chapter 1 Classification of hydropower projects, hydropower and the environment: present context and guidelines for future action subtask 5 Report, vol. II main report; 2000.
[4] Paish O. Small hydro power: technology and current status. Renew Sustain Energy Rev 2002;6:537–56.
[5] ESHA (European Small Hydropower Association). Guide on how to develop a small hydropower plant. http://www.esha.be/fileadmin/esha_files/documents/publications/publications/Part_1_Guide_on_how_to_develop_a_small_hydropower_plant-_Final.pdf; 2004.
[6] Demirmas A. Potential applications of renewable energy sources, biomass combustion problems in boiler power systems and combustion related environmental issues. Prog Energy Combust Sci 2005;31:171–92.
[7] Dudhani S, Sinha AK, Inamdar SS. Assessment of small hydropower potential using remote sensing data for sustainable development in India. Energy Policy 2006;34:3195–205.
[8] Kaldellis JK. The contribution of small hydro power stations to the electricity generation in Greece: technical and economic considerations. Energy Policy 2006;35:2187–96.
[9] Tsoutsos T, Maria E, Mathioudakis V. Sustainable siting procedure of small hydroelectric plants: the Greek experience. Energy Policy 2007;35: 2946–59.
[10] Ramachandra TV, Shruthi BV. Spatial mapping of renewable energy potential. Renew Sustain Energy Rev 2007;11(7):1460–80.
[11] Belmonte S, Nunez V, Viramonte JG, Franco J. Potential renewable energy resources of the Lerma Valley, Salta, Argentina for its strategic territorial planning. Renew Sustain Energy Rev 2008;13(6):1475–84.
[12] Jankowski P. Integrating geographical information systems and multiple criteria decision-making methods. Int J Geograph Inf Syst 1995;9(3): 251–73.
[13] Melo ALO, Calijuri ML, Duarte ICD, Azevedo RF, Lorentz JF. Strategic decision analysis for selection of landfill sites. J Surv Eng 2006;132(2):83–92.
[14] Forzieri G, Gardenti M, Caparrini F, Castelli F. A methodology for the preselection of suitable sites for surface and underground small dams in arid areas: a case study in the region of Kidal, Mali. Phys Chem Earth 2007;33(1):74–85.
[15] Creighton JL. The public participation handbook: making better decisions through citizen involvement. San Francisco: Jossie-Bass; 2005.
[16] Delli Priscoli J. Public involvement conflict management: mean to EQ and social objective. J Water Resource Plan Manage 1989;115(1):31–42.
[17] World Bank. Environmental Assessment Sourcebook, vol. 1. World Bank Technical Paper No. 139. Washington DC: World Bank; 1991.
[18] Bureau of Committee 3, the Secretariat of the House of Representatives. Constitution of the Kingdom of Thailand, B.E. 2550 (2007). First ed. Bangkok: Bureau of Printing Services, the Secretariat of the House of Representatives; 2007.
[19] Vaughn S, Shay-Schumm J, Sinagub J. Focus group interviews in education and psychology. Thousand Oaks, CA: Sage; 1996.
[20] ASA (American Statistical Association). ASA Series: what is a survey? What are focus groups? Alexandria, USA: Section on Survey Research Methods; 1998.
[21] Armour AM. Social impact assessment. The Canadian Encyclopedia. http://www.thecanadianencyclopedia.com/index.cfm?PgNm=TCE&Params=A1SC828275; 2008.
[22] EGAT (Electricity Generating Authority of Thailand). Thailand Power Development Plan (PDP 2007), Presented to High Level Forum on Lao-Thai Partnership in Sustainable Hydropower Development, 7 September 2007, Shangri-La Hotel, Bangkok, Thailand, http://siteresources.worldbank.org/INTTHAILAND/Resources/333200-1089943634036/475256-1151398858396/2007sept-hydro_presentation_prutichai.pdf; 2007.
[23] DEDE (Department of Alternative Energy Development and Efficiency). The small hydropower project development in Thailand. Bangkok: Ministry of Science Technology and Environment; 2006.
[24] NEF (New Energy Foundation). Guide manual for development aid programs and studies of hydro electric power projects. Tokyo, Japan: Hydroelectric Power Development Center, New Energy Foundation; 1996.
[25] RID (Royal Irrigation Department). The Nan river basin development project: Integration plan of river basin development. Thailand: Ministry of Agriculture and Cooperatives; 2005.
[26] ESRI (Environmental Systems Research Institute). Using ArcGIS Spatial Analyst. Redlands: ESRI; 2002.
[27] Burke R. Getting to know ArcObjects programming ArcGIS with VBA. Redlands: ESRI; 2003.
[28] Chaisomphpb T, Tanutpongpalin N. Application of geographic information system to site selection of run-of-river type small hydropower project based on environmental criteria. Eng Inst Thailand Res Dev J 2004;15(4): 37–47.
[29] Rojanamon P, Chaisomphob T, Rattanapitikon W. Regional flow duration model for the Salawin river basin of Thailand. ScienceAsia J Sci Soc Thailand 2007;33:411–9.
[30] Singh KP. Model flow duration and stream flow variability. Water Resource Res 1971;7(4):1031–6.
[31] Quimpo RG, Alejandrino AA, McNally TA. Regionalized flow duration for Philippines. J Water Resources Plan Manage 1983;109(4):320–30.
[32] Kjelstrom LC. Methods for estimating selected flow-duration and flood-frequency characteristics at ungauged sites in Central Idaho. Water-Resources

Investigations Report 94-4120. U.S. Department of the Interior, U.S. Geological Survey, prepared in cooperation with U.S. Bureau of Indian Affairs, Boise, Idaho, http://www.earth.boisestate.edu/home/jmcnamar/hydanalysis/2008/kjelstrom.pdf; 1998.
[33] Singh RD, Mishra SK, Chowdhary H. Regional flow-duration models for large number of ungauged Himalayan catchments for planning microhydro projects. J Hydrolog Eng 2001;6(4):310–6.
[34] Castellarin A, Camorani G, Brath A. Predicting annual and long-term flow-duration curves in ungauged basins. Adv Water Resources 2007;30:937–53.
[35] Burrough PA. Principles of Geographical Information Systems for land resources assessment. New York: Oxford University Press; 1986. p. 6–7.
[36] Elliott CR. Small hydropower for Asian rural development, the proceedings of a workshop on small scale hydropower technology application in Asian rural settings. Thailand: Asian Institute of Technology; 1981.
[37] Inversin AR. Micro-hydropower sourcebook, a practical guide to design and implementation in developing countries. Arlington, VA: NRECA International Foundation; 1986.
[38] Harvey A, Brown A, Hettiarachi P, Inversin A. Micro-hydro design manual, a guide to small-scale water power schemes. UK: Intermediate technology publication; 1993.
[39] NEA (National Energy Administration). Master plan of mini/micro hydropower to replace diesel power plants. Thailand: Ministry of Science Technology and Energy; 1983.
[40] DEDP (Department of Energy Development and Promotion). The study of master plan on small hydropower project development in Thailand. Bangkok: Ministry of Science Technology and Environment; 2004.
[41] DEDE (Department of Alternative Energy Development and Efficiency). Feasibility study on Khaew Noi small hydropower project, Phitsanulok Province (Final Report). Bangkok, Thailand: Ministry of Energy; 2006.
[42] EGAT (Electricity Generating Authority of Thailand). The feasibility study of Mae Hong Son small hydropower project. Nonthaburi, Thailand: Hydro Power Engineering Department; 2007.
[43] National Statistical Office of Thailand. The Nan provincial statistical report. Thailand: Ministry of information and communication technology; 2007.
[44] NEA (National Energy Administration). Master plan of mini hydropower development (Final Report), Ministry of Science Technology and Energy; 1988 (in Thai).
[45] DEA (Department of Energy Affairs). Master plan of micro hydropower project in Thailand. Ministry of Science Technology and Environment, Bangkok, Thailand; 1993. p. 4–11 (in Thai).